Optical detection of microwave resonance in germanium by means of luminescence of electron-hole drops

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Microwave resonance in germanium was registered by means of the change of the intensity of the luminescence of electron-hole drops (EHD). A resonant decrease of the luminescence of the EHD was observed at the cyclotron-resonance frequencies of the free carriers. At large microwave powers, an intense line that did not agree with the cyclotron-resonance spectrum was observed.

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Cyclotron resonance on free carriers in germanium was observed[1] under conditions when electron-hole drops were present. In this study, the cyclotron resonance was observed by the usual method, i.e., from the absorption

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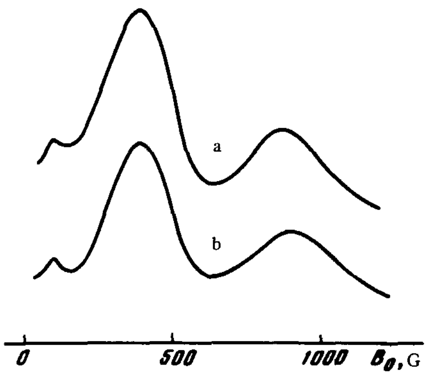

FIG. 1. Spectrum of microwave resonance in germanium, determined from the change of the intensity of the EHD luminescence (a) and from the absorption of the microwave power (b): $T = 1.8$ K, $P_{\mathrm{microwave}} \approx 1$ mW, $B_0 \parallel [100]$.

of the microwave power. Absorption of microwave power was used in[2] to register EPR on shallow donors in germanium.

In the present study we used, for the first time, an optical-detection method to observe microwave resonance in germanium. At high excitation densities and at low temperatures, electron-hole drops (EHD) are formed in germanium and produce intense recombination luminescence with a photon energy 0.709 eV.[3] The microwave resonance was detected by us from the change of the intensity of the EHD recombination luminescence.

Samples of pure germanium with residual impurity concentration $N_A \leq 10^{12}$ cm^{-3} measured $2\times3\times1$ or $1\times3\times0.5$ mm. These samples were placed in the antinode of the magnetic field of a rectangular resonator at the H_{012} mode and frequency $\nu = 9000$ MHz. The alternating field in the resonator was perpendicular to the constant magnetic field B_0. The field B_0 was produced by two coils with superconducting windings. The EHD were excited by helium-neon laser light focused on the sample with wavelength 6328 Å and power 50 mW, directed along or perpendicular to the constant magnetic field. The luminescence was registered in the direction of the field B_0. The experiments

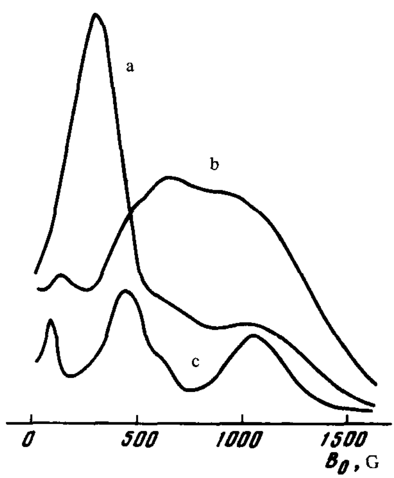

FIG. 2. Spectrum of microwave resonance in germanium, determined from the change of the intensity of the EHD luminescence (a) and from the absorption of the microwave power (b): $T = 1.8$ K, $P_{\mathrm{microwave}} \approx 150$ mW, $B_0 \parallel [111]$. The spectrum (c) was determined from the microwave-power absorption at $P_{\mathrm{microwave}} \approx 2$ mW.

were performed at a temperature 1.8 K. No exciton luminescence was observed in these experiments.

The microwave resonance was revealed by the change in the intensity of recombination luminescence of the EHD. We used either modulation of the exciting light or modulation of the microwave power. The resonance was registered simultaneously also by determining the change of the absorption of the microwave power in the sample.

Figure 1 shows the microwave-resonance spectra registered by means of luminescence (a) and by absorption of the microwave power (b). The magnetic field B_0 was parallel to the [100] axis of the sample. The microwave power fed to the resonator was ~ 1 mW. The spectra shown in Figs. 1(a) and 1(b) are almost identical and practically coincide with the spectrum of the cyclotron resonance in germanium. Since the spectrum (b), determined from absorption of the microwave power, was observed by us also in the absence of EHD (in weak optical excitation and at a higher temperature), it can be attributed to ordinary cyclotron resonance in germanium. This resonance is excited by the weak component of the alternating electric field present in the sample and perpendicular to the constant field B_0. Thus, the spectrum of Fig. 1(a), registered by the optical-detection method, is the cyclotron-resonance spectrum of the electron and holes in the germanium. To our knowledge, this is the first observation of optical detection of cyclotron resonance.

The spectrum in Fig. 1(a) can be explained in the following manner. It appears that the free electrons and holes, after absorbing microwave power by cyclotron resonance, are heated, act on the EHD, and cause evaporation of the drops and a decrease in the intensity of their recombination luminescence.

The influence of microwave exciton breakdown on the luminescence of EHD in germanium was observed in[4] and attributed there to the action of the phonon wind produced by the hot carriers. It is possible that the effect observed by us can also be attributed to the action of the phonon wind produced by carriers heated by cyclotron resonance.

Increasing the microwave power in the resonator to 100—200 mW leads to substantial changes in the microwave-resonance spectra. A strong difference is then observed between the spectra determined from the EHD luminescence (Fig. 2a) and from the absorption of the microwave power (Fig. 2b). In this experiment the magnetic field B_0 was directed along the [111] axis of the sample.

Spectrum 2(b) shows a broadening of the cyclotron-resonance line due to heating of the carriers. For comparison, Fig. 2(c) shows the spectrum determined from the absorption of the microwave power at low microwave power in the resonator (~ 2 mW).

The spectrum (a) of Fig. 2 shows an intense line in the region of 400 G, a line not seen in (b) and (c). This line at the maximum corresponds to an abrupt decrease of the EHD luminescence intensities by as much as 30%. This line appears only when the microwave power in the resonator exceeds ~ 10 mW, and increases sharply with increasing power. At lower microwave powers it is apparently masked by the cyclotron-resonance signal. A decrease of the exciting-light intensity by a factor of five narrows this line by a factor of 1.5.

The spectrum (a) of Fig. 2 does not correspond to ordinary cyclotron resonance. The origin of the observed lines is still not clear. It can only be assumed that it is due either to paramagnetic resonance of the electrons in the EHD, or to cyclotron resonance induced in the EHD.[5] In this case, the EHD can also be heated as a result of absorption of microwave power, and the luminescence intensity can change as a result of the evaporation of the EHD.

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